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Facilitated Access to the Space environment for Technology development and training (FAST)

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Technology infusion into NASA programs and projects is a priority for NASA's Innovative Partnerships Program (IPP). A big challenge to technology infusion is the perceived risk by program/project managers, and they generally desire technologies to be at technology readiness level (TRL) 6 by their preliminary design review (PDR). A key element of achieving TRL 6 is demonstrating a technology in the relevant environment, including the gravity environment – from microgravity to lunar or Martian gravity levels. IPP is initiating a new activity – Facilitated Access to the Space environment for Technology development and training (FAST) – to provide more opportunities for advancing TRLs by providing partnership opportunities to demonstrate technologies in these environments. Currently, space technology development often stalls at the mid-technology readiness levels due to lack of opportunities to test prototypes in relevant environments. In addition, limited testing opportunities often have high associated costs or require lengthy waits. NASA recently selected a commercial service provider for parabolic aircraft flight to simulate multiple gravity environments. FAST will purchase services through this new procurement mechanism and provide partnership opportunities aimed at advancing needed space technologies to higher technology readiness levels (TRL). The objective is to provide advanced technologies with risk levels that enable more infusion, meeting the priorities of NASA's Mission Directorates and their Programs and Projects.

Nomenclature

COTS	=	*Commercial Orbital Transportation Services*
FAST	=	*Facilitated Access to the Space environment for Technology development and training*
IPP	=	*Innovative Partnerships Program*
MD	=	*Mission Directorate*
PDR	=	*Preliminary Design Review*
R&D	=	*research and development*
SBIR	=	*Small Business Innovation Research*
SCAP	=	*Strategic Capability Assets Program*
STTR	=	*Small Business Technology Transfer*
TRL	=	*Technology Readiness Level*

I. Introduction

NASA's Innovative Partnerships Program (IPP) provides needed technology and capabilities for NASA's Mission Directorates, Programs, and Projects through leveraged investments and partnerships with Industry, Academia, Government Agencies, and National Laboratories. A key strategic goal of NASA's Innovative Partnerships Program (IPP) is Technology Infusion – providing technical solutions to challenges being faced by NASA's programs and projects. As one of NASA's Mission Support Offices, IPP supports all four Mission Directorates and has Program Offices at each of the NASA Centers.

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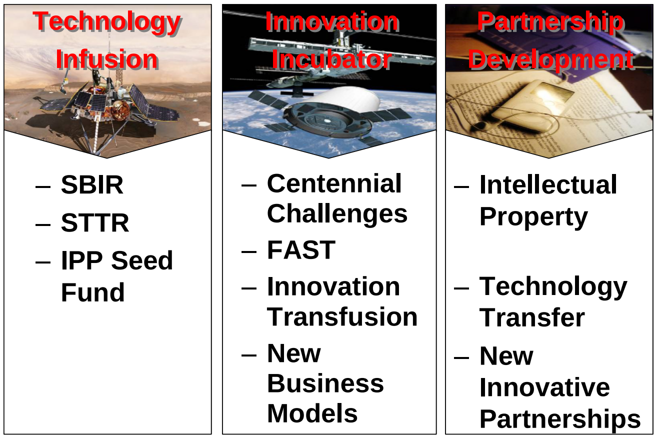

Figure 1 – Elements of NASA's Innovative Partnerships Program.

In addition to leveraged technology investments, dual-use technology-related partnerships, and technology solutions for NASA, IPP enables cost avoidance, and accelerates technology maturation[1]. IPP consists of the following program elements, as summarized in Figure 1: Technology Infusion which includes the Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) Programs and the IPP Seed Fund; Innovation Incubator which includes Centennial Challenges, and new efforts such as facilitating the purchase of services from the emerging commercial space sector; and Partnership Development which includes Intellectual Property Management and Technology Transfer, and new innovative partnerships. Together these program elements increase NASA's connection to emerging technologies in external communities, enable targeted positioning of NASA's technology portfolio in selected areas, and secure NASA's intellectual property to provide fair access and to support NASA's strategic goals. Technology transfer through dual-use partnerships and licensing also creates many important socio-economic benefits within the broader community[2].

The general process by which IPP develops and provides technology to meet the needs of NASA's Mission Directorates is provided in Figure 2. The biggest obstacle to technology infusion is the perceived risk by program/project managers (or their systems engineers) of adopting a new technology. They like to have technologies with flight heritage and don't want to take on any more risk than they feel they have to. If the benefits of a new technology don't clearly outweigh the risks in the mind of a decision-maker, than that technology will likely not be infused. Projects generally desire technologies to be at least TRL 6 by their preliminary design review (PDR). A key element of achieving TRL 6 is demonstrating a technology in the relevant environment, including the gravity environment – from microgravity to lunar or Martian gravity levels. Space technology development can stall at the mid-technology readiness levels due to lack of opportunities to test prototypes in relevant environments. In addition, limited testing opportunities often have high associated costs or require lengthy waits. To create more opportunities to advance the maturity of key technologies, reduce the perceived risk of adopting those technologies, and thereby increase the likelihood of more technology infusion, IPP is establishing a project named Facilitated Access to the Space environment for Technology development and training (FAST).

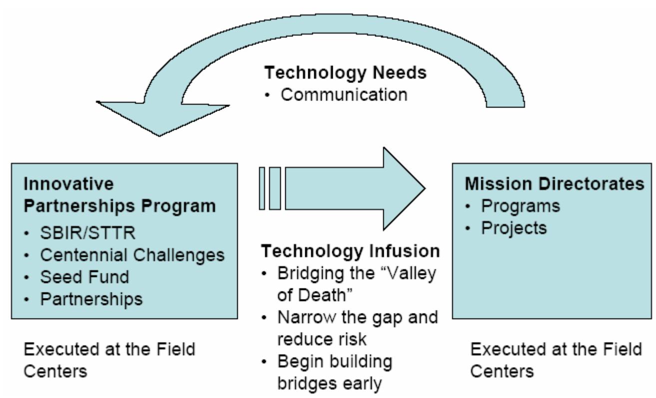

Figure 2 – IPP's technology portfolio is intended to address the needs of NASA's Mission Directorates.

II. Technology Infusion

Technology Infusion is an increasingly important function for NASA, given limited resources for technology development within the Agency. IPP's portfolio allows leveraging of partner expertise and funds to achieve NASA's research and development (R&D) goals. There are several sources of technology in the IPP portfolio that have potential for addressing the needs of the Mission Directorates. These include SBIR/STTR, Centennial Challenges, and the IPP Seed Fund. Institutions in industry and academia that are currently conducting independent R&D may provide technical solutions that can be utilized by NASA through partnerships. These partnerships also allow internal NASA technology development funding to be leveraged with external organizations through work agreements with joint goals. Technology Infusion allows capabilities of both NASA and partners to be utilized allowing accelerated technology maturation through concurrent R&D and collaboration. Thus, Technology Infusion not only provides benefits to NASA but also to its partners.

The largest portion of IPP's technology portfolio comes from small businesses that are funded by NASA's SBIR/STTR programs. SBIR and STTR are competitive programs that provide technology to address NASA's needs. SBIR is for small businesses (less than 500 employees), and STTR requires that small businesses partner with a research institution (e.g. a University or Federal laboratory) with the objective of transferring research from the laboratory to the small business where it can be further developed and put to commercial use. Each year NASA awards several hundred contracts to small businesses and their partners.

Table 1 – Technology taxonomy for NASA's SBIR and STTR Programs.

NASA SBIR/STTR Technology Taxonomy

- **Avionics and Astrionics**
- **Biotechnology**
- **Communications**
- **Cryogenics**
- **Education**
- **Electronics**
- **Extravehicular Activity**
- **Information**
- **Manufacturing**
- **Materials**
- **Microgravity**
- **Power and Energy**
- **Propulsion**
- **Robotics**
- **Sensors and Sources**
- **Structures**
- **Thermal**
- **Verification and Validation**

The purposes of the SBIR/STTR programs, as established by law, are to stimulate technological innovation in the private sector; to strengthen the role of small businesses in meeting Federal research and development needs; to increase the commercial application of these research results; and to encourage participation of socially and economically disadvantaged persons and women-owned small businesses[3]. To be eligible for selection, a proposal must present an innovation that meets the technology needs of NASA programs and projects and has significant potential for successful commercialization – which encompasses the transition of technology into products and services for NASA mission programs, other Government agencies and non-Government markets. A summary of the types of technologies NASA is interested in is represented by the SBIR/STTR technology taxonomy in Table 1.

The IPP Seed Fund has been established as an annual process to enhance NASA's ability to meet mission technology goals by providing seed funding to address barriers and initiate cost-shared, joint-development partnerships. The IPP Seed Fund is used to provide 'seed' funding to enable larger partnerships and development efforts to occur and will encourage, to the maximum extent possible, the leveraging of funding, resources, and expertise from non-NASA partners, NASA Programs and Projects and NASA Centers. Proposed projects should be one year in duration and must include one or more non-NASA partners who are willing to provide cost-sharing at a level equal to or greater than the IPP funding provided to the project. Acceptable cost-sharing from the partner includes actual dollars applied directly to the project, in-kind considerations such as workforce labor and the use of unique and dedicated facilities and testbeds. Such leveraging of non-NASA resources also helps ensure successful application of the technology, because the partners have 'skin in the game' as stakeholders. The technology landscape covered by the successful proposals embraces the needs of all four Mission Directorates.

Centennial Challenges is NASA's program of prize contests to stimulate innovation and competition in solar system exploration and ongoing NASA mission areas. By making awards based on actual achievements, instead of proposals, Centennial Challenges seeks novel solutions to NASA's mission challenges from non-traditional sources of innovation in academia, industry and the public.

The ultimate objective of investments in all these elements of IPP's technology development portfolio is to achieve infusion of the technological innovations developed into NASA's programs and projects. Successfully maturing technologies to reduce the risk of infusion is a key factor in success. Technology maturity is measured by conducting TRL assessments that determine the maturity of the technology. TRLs reflect a systematic metric/measurement system that supports assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology. The TRL approach, with levels summarized in Table 2, has been used in NASA space technology planning for many years[4].

As an example of how IPP uses TRLs to track the maturity of technologies in the portfolio, planned technology advancement resulting from the 2006 seed fund awards is illustrated in Figure 3.

Table 2 – Technology Readiness Levels Summary

TRL 1	Basic principles observed and reported.
TRL 2	Technology concept and/or application formulated.
TRL 3	Analytical and experimental critical function and/or characteristic proof-of concept.
TRL 4	Component and/or breadboard validation in laboratory environment.
TRL 5	Component and/or breadboard validation in ***relevant environment***.
TRL 6	System/subsystem model or prototype demonstration in a ***relevant environment*** (ground or space).
TRL 7	System prototype demonstration in a ***space environment***.
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space).
TRL 9	Actual system "flight proven" through successful mission operations.

The number of 2006 Seed Fund projects at each TRL is shown in the blue at the time of the award, and in red at the planned level after the one year seed fund project.

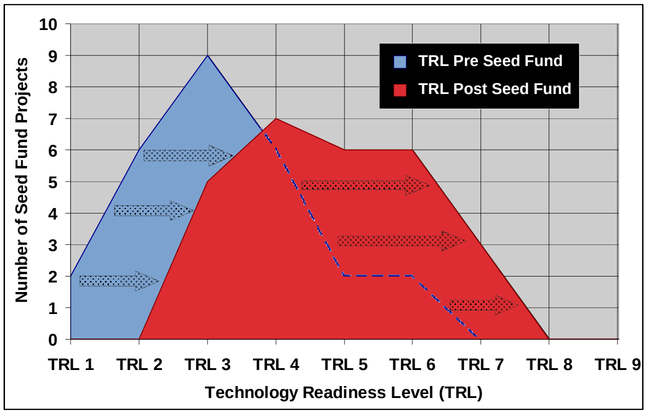

Figure 3 – Technology maturation expected from FY 2006 Seed Fund projects.

Note from Table 2 the importance of demonstrating technology in the *relevant environment*, particularly to achieve TRL 5-7. Most often this includes a gravity environment that may differ from the Earth's whether it be microgravity, lunar, or Martian. However, opportunities to test technologies and corresponding subsystems in other gravity levels are limited, and those that offer best results can be lengthy and expensive. Providing more routine and affordable access to the relevant environment to advance technology maturity is precisely the focus of the FAST project.

By providing more opportunities to demonstrate technologies in the relevant environments, advance their maturity and reduce the risk of infusing them, IPP will be increasing the likelihood that more technologies will be infused.

III. Microgravity Environment Simulation

There are several different methods to achieve a reduced gravity environment to validate technology development and each method comes with its own benefits and drawbacks. The methods can be considered a stairstep of capability that provides improves at each step in terms of time in the environment and quality of the environment, but correspondingly increases in cost. The methods include: drop towers; parabolic aircraft flights; suborbital flights with sounding rockets or emerging reusable suborbital flights; orbital flights on the Shuttle, to the ISS or on other spacecraft; variable gravity on-orbit through the use of a centrifuge; and demonstrations on other planetary bodies (e.g. the lunar surface).

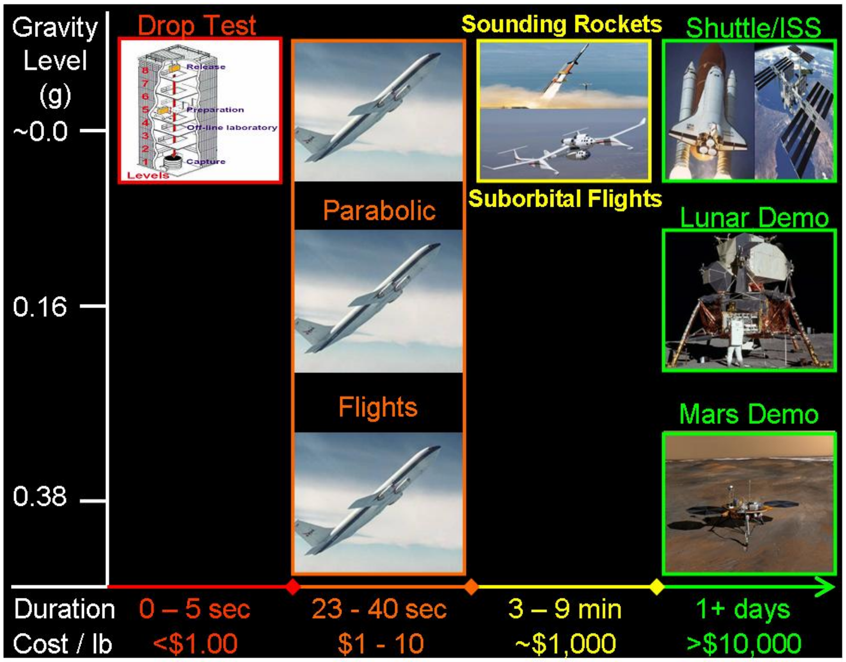

Figure 4 – There are many methods to provide reduced gravity environments for technology demonstrations, and they vary significantly in duration and cost.

As illustrated in Figure 4, the drop test is the cheapest method, costing only pennies per pound, to achieve a microgravity environment; however it is also the shortest in duration measured in seconds. Drop tests consist of a payload being dropped in specially designed facilities and allowed to freefall. Drop tests also require access to limited facilities to perform such tests. The next cheapest method of achieving a reduced gravity environment is parabolic flights. Airplanes perform parabolic maneuvers which create a simulated reduced gravity environment. These maneuvers can simulate a multitude of reduced gravity levels, including microgravity, Lunar and Martian; however are limited in duration of approximately 25 seconds per parabolic maneuver.[5]

Greater payloads can be accommodated on parabolic flights, being limited only by the size of the plane. Each flight usually consists of 40-60 parabolic maneuvers and costs in the tens of thousands of dollars. Sounding rockets and reusable suborbital vehicles offer alternatives that can increase the duration of the microgravity simulation to a few minutes. These methods reach an altitude great enough to coast through space and create a microgravity environment, but not high enough to reach orbit. The period of microgravity lasts a few minutes until the vehicles begin to re-enter the atmosphere. Costs for these lengthier periods of microgravity simulation begin to escalate with sounding rockets, which are on the order of a million dollars per test. Several commercial vehicles that plan to provide suborbital launch services and a microgravity environment with reusable piloted vehicles are now in development. They are expected to provide a lower-cost alternative that could complement sounding rocket experiments. Experiments on the Shuttle, International Space Station, or other orbital spacecraft offer the longest duration in experiments, and are only limited by the time that they are aboard such spacecraft. These tests, although the most precise, are the most expensive of the group and can run in the tens of thousands of dollars per pound. Each method, due to its limitations and benefits, has its place and must be determined according to the requirements of the technology development.

IV. NASA Microgravity Flight Procurement

NASA has been flying parabolic flights on NASA-owned KC-135 and C-9B aircraft for decades out of Ellington Field under the management of JSC's Reduced Gravity Office. Those flights have made numerous contributions to scientific advancement and technology development. There are now commercial providers who offer the microgravity flight capability on a routine basis. NASA has pursued purchasing services to provide this capability on a commercial basis. At the bidders conference for the procurement, the former NASA Associate Administrator, Rex Geveden, made the following remarks[6]:

> *"The Microgravity Flight Procurement is a notable example of NASA's commitment to advancing this nation's space capability by leveraging private investments and exploiting commercial efficiencies for the dual purposes of supporting the execution of NASA's missions and encouraging the development of commercial space markets.*
>
> *During his confirmation hearing before the U.S. Senate on April 13th, 2005, NASA Administrator Michael Griffin outlined six strategic priorities for NASA, one of which was to "encourage the pursuit of appropriate partnerships with the emerging commercial space sector." Those six strategic priorities later became the foundation of NASA's Strategic Plan published early in 2006.*
>
> *In general, encouraging the commercial space sector means that NASA will contract, under commercial arrangements, for goods and services, some of which have been historically provided by the government itself or acquired through research and development cost-type contracts. In other cases, where markets are less than fully developed and commercial entities cannot yet close the business case or in which the barriers to entry are prohibitive, NASA may co-invest with a commercial concern in order to develop a capability. In the latter case, it is hoped that NASA's investment will lead to the development of an efficient market that will justify the original investment.*
>
> *The Microgravity Flight Services Procurement is an example of the former, and our Commercial Orbital Transportation Services (COTS) effort is an example of the latter. These two efforts—Microgravity Flight Services and COTS—have strategic and symbolic importance to the Agency, as they represent, not only partial fulfillment of our strategic objectives, but also relevant examples of a new way of doing business with NASA.*
>
> *Another way to describe our strategy is that we intend to commoditize routine and stable aspects of space exploration in order to take full advantage of commercial efficiencies. Doing so reduces the cost and improves reliability while it liberates NASA to concentrate its resources on a more appropriate government role--pursuing those activities that require the nation's investment but for which the business case does not yet close."*

NASA just completed this procurement to select a commercial service provider for parabolic aircraft flight to simulate multiple gravity environments, awarding the contract to the Zero Gravity Corporation (ZERO-G) on January 2, 2008. IPP is working with NASA's Strategic Capability Assets Program (SCAP) and the Glenn Research Center (GRC) who have responsibility for this procurement, to use this IDIQ contract for parabolic aircraft services in support of the new project that is the subject of this paper – Facilitated Access to the Space environment for Technology development and training (FAST).

In fulfillment of this contract, ZERO-G will provide up to 20 Reduced Gravity Flight Weeks per year. A Flight Week begins on Monday with a test readiness review followed by aircraft loading, and flights conducted each day Tuesday through Friday. Each flight includes 40-60 reduced gravity parabolic trajectories as shown in Figure 5. Aircraft unloading is conducted on Friday after the flight is completed. The aircraft is considered "exclusive use" to NASA during a flight week. Flight Weeks will be conducted out of Ellington Field in Houston, Texas; and the Glenn Research Center in Cleveland, Ohio. The cabin can accommodate rigid experiment racks weighing up to 1,400 lbs and measuring up to 96 inches in length, 60 inches in width. The aircraft will provide near zero gravity conditions, partial gravity conditions at Lunar (.16 g), and Martian (.38 g) gravities, as well as other partial gravity levels. The aircraft can also provide sustained hyper gravity conditions, up to 1.8 g in .10 g increments, for periods of up to 1 minute in duration.

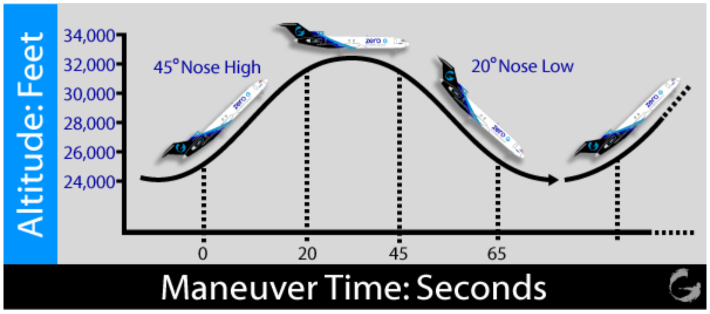

Figure 5 – Typical parabolic flight profile of the ZERO-G aircraft.

V. FAST Plans

FAST has the dual objectives of demonstrating the purchase of commercial services from the emerging commercial space sector, and advancing technology maturity through use of those services. Initially, FAST will focus on use of this new parabolic flight service for technology development support. As suborbital flights become available, the FAST project will seek to use those services as well – initially for technology development and eventually to support potential training needs in the future. FAST will purchase services through this new procurement mechanism and provide partnership opportunities aimed at reducing risk by advancing needed space technologies to higher technology readiness levels (TRL), as illustrated in Figure 6. This will demonstrate the business model for purchasing services commercially, and advance technology readiness for NASA's research and technology needs. The goal is to provide advanced technologies with risk levels that enable more infusion, meeting the priorities of NASA's Mission Directorates and their Programs and Projects.

To achieve the strategic goal of the FAST activity, certain key objectives must be met. The first objective includes demonstrating effective use of procurement of commercial space services by NASA to advance Agency missions. Ensuring that the procured parabolic flight services can actual serve to benefit NASA is a key objective because it offers insight to how future commercial space sector services will be utilized in the future. To partner with the commercial space sector for the sake of partnering adds no benefit to either party, and adds no credence to why partnerships should continue between the two. Thus, the FAST activity looks to fully utilize the procured services to advance technology development by adding another source of testing in microgravity environments. Therefore, FAST purchased services through this new procurement mechanism and will utilize the time to catalyze partnership opportunities aimed at advancing needed space technologies to higher TRLs. The FAST project initially plans two flight-weeks worth of services dedicated to these partnerships.

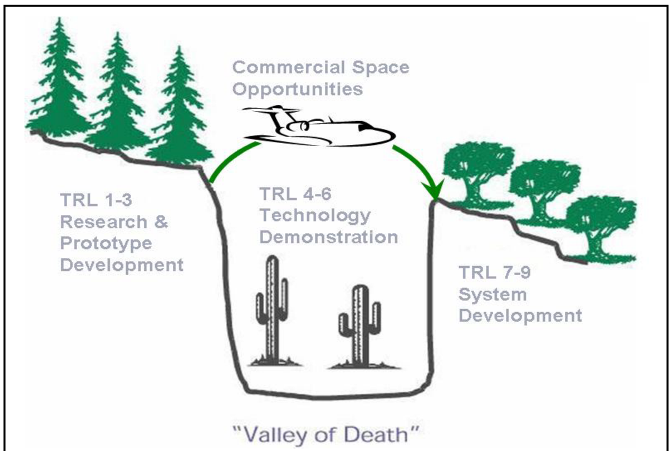

Figure 6 – Commercial services, beginning with parabolic microgravity flights, will help bridge the technology development 'valley of death.'.

The second objective is to provide competitive access to the commercial microgravity flight services in order to initiate the cost-shared partnerships focusing on advancing technologies of interest to NASA. The process for selecting technology development partnerships for microgravity flight services is similar to the IPP Seed Fund selection process.

An IPP Call will be released from the NASA Headquarters IPP Office in the spring of 2008 soliciting proposals for cost-shared partnerships targeted at technologies in the IPP portfolio, particularly SBIR/STTR technologies and Seed Fund projects, but will also be open to new partnerships with industry, academia, research institutions, national laboratories and other government agencies. The objective is joint development of technology that is of primary interest to NASA and will advance TRLs after successful demonstration in the appropriate reduced-gravity environment. Assessment of possible partners will be conducted through NASA mission directorates and the center IPP offices. Interest from possible partners will also be solicited externally through a release on the FedBizOpps website. Interested parties can contact Center IPP offices to learn more about how they can be considered for partnership opportunities. Proposal submission will be coordinated through the IPP office at each Center. Final selection of proposals and partners will be determined by the NASA Headquarters IPP office and the four Mission Directorates. Proposal selection will be based upon the relevance of the proposed technology advancement to NASA's needs, the technology advancement achieved by the flight, and partner contributions to the partnership. This includes technologies that are part of the NASA Mission Directorate technology roadmaps, and other technologies deemed of up most importance by the individual NASA centers. Only technologies that require relevant environmental testing in reduced (1/3 Mars, 1/6 for Lunar) or microgravity to advance TRL will be considered in the selection.

Selected partnerships will be managed by center IPP offices and will not focus on new developmental work for the technology, but rather on readying the technology for microgravity flights aboard the parabolic aircraft. FAST will provide one element of a larger technology development effort that will vary by technology, but the common objective is to demonstrate that the technology does or does not work in the relevant environment and therefore advance the maturity of the technology. After the readying work is completed, a "Pre-flight Review" will be conducted to inspect the technology development progress. During which time NASA engineers will make sure that the technology experiment meets design specifications set by NASA's Aircraft Operations Division.[7] Once verified, flight weeks will be manifested for the selected partnerships.

IPP has planned for funding to pursue joint technology development partnerships with the selected organizations. This funding will be utilized to cost-share technology readying and the microgravity flight between both entities and a sponsoring NASA program or project. Similar to the Seed Fund, NASA programs and projects will be expected to put 'skin in the game' in order to ensure that the technology is of importance to NASA. It will be required that the external partner provide at least an equal share of funding for the partnership to succeed. Cost-sharing the technology development will spread risk and will ensure that TRL advancement will benefit all involved.

A new governance model will be utilized by NASA to determine internal priority for the Microgravity Flight Services. This new structure will shorten the duration between the time when a microgravity parabolic flight is requested and when the service will be provided. The new governance model consists of a panel with representatives from all NASA Mission Directorates, IPP, SCAP, and the Education office that will determine priority for flight services, and will allow projects with strategic importance to the agency to take high priority. Thus, partnerships between a NASA program or project, IPP, and a partner on a NASA-needed technology should fare well when flight weeks are scheduled. This opportunity allows partners a unique opportunity to circumvent the long wait for microgravity flight testing.

At completion of the microgravity flight testing, technologies should reach TRL 5 or 6 and be ready for Technology Infusion. Perceived risk by NASA managers of partner technologies is reduced at TRL 5 and 6 and so there is a greater likelihood that the technologies are incorporated into programs, projects, and missions. Perceived risk by program managers is further mitigated by having both IPP and another NASA program or project sponsoring the technology advancement. This demonstrates to program managers that the technology and the partner can keep to NASA requirements and are familiar with the agency's needs and procurement.

VI. Conclusion

FAST has the dual objectives of demonstrating the purchase of commercial services from the emerging commercial space sector, and advancing technology maturity through use of those services. Should the initial efforts for utilizing commercially-provided services prove to be a success, the FAST activity may extend its services to include other capabilities. A priority for NASA is to encourage the development and use of the reusable suborbital flight capability that is being developed commercially. This may offer further opportunities to the commercial space sector and also allow NASA to further achieve its fifth strategic goal. Other possibilities that FAST may look to incorporate include 'shared rides' on sounding rockets or orbital vehicles, and space environment training facilities. The next step is to demonstrate how these services may be utilized by NASA and its partners to increase benefits for all. The goal is to eventually extend this model of commercial space service procurement to a standard business practice within NASA, including use of suborbital flight services when they become available.

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